(19) Europäisches Pat ntamt
European Patent Offic
Office européen d s brevets

(11) Publication number: **0 067 494 A1**

(12) EUROPEAN PATENT APPLICATION

(21) Application number: 82300511.1

(22) Date of filing: 01.02.82

(51) Int. Cl.3: B 23 K 35/368
B 23 K 35/30

(30) Priority: 03.06.81 US 270160

(43) Date of publication of application: 22.12.82 Bulletin 82/51

(84) Designated Contracting States: DE FR GB IT NL SE

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(54) Welding electrode.

(57) A flux-cored, gas shielded welding electrode is disclosed having a generally tubular sheath and a core defined within the sheath, wherein the core includes a slag forming system consisting essentially of from 3 to 12 percent titanium dioxide, 0 to less than 0.2 percent magnesium oxide, less than 2 percent calcium fluoride, and from 0.1 to 1.0 percent sodium oxide, potassium oxide or other arc stabilizer, 0.2 to 2.0 percent silicon, and 0.5 to 4.5 percent manganese, based on the total electrode weight. The electrode of the present invention further includes from .003 to .08 percent boron based on the total electrode weight.

WELDING ELECTRODE

The present invention is directed to welding electrodes, and more particularly, to flux-cored welding electrodes wherein the core includes a specific rutile based slag system with a small amount of boron added thereto, wherein the slag system includes little or no magnesium oxide.

Various welding electrode compositions are disclosed in the prior art. For example, United States Patent No. 3,868,487 discloses a flux-cored wire for submerged arc welding which contains a large proportion of calcium fluoride. Also United States Patent No. 3, 924,091 pertains to a cored welding wire of neutral composition, i.e., having a basicity in the range of about 0.90 to 1.30. United States Patent No. 4,029,934 relates to a solid steel welding wire which may contain .002 to .008% boron in steel. And United States Patent No. 4, 125,758 teaches the use of a consumable strip electrode which may contain boron.

A commercially acceptable flux-cored continuous welding electrode is disclosed in United States Patent No. 3,051,822. Such electrode is employed in a welding process which utilizes a dual principal for shielding the welding

operation. In particular, a slag is formed during welding to shield the molten weld metal, and a gas is used simultaneously to shield the arc column. An improved welding electrode, particularly adapted for use in vertical or other out-of-position welding is disclosed in United States Patent No. 3,800,120. The slag system employed in these contemporary, gas shielded, flux-cored electrodes are based, primarily, on titanium dioxide.

It appears that welds deposited with an electrode having a titanium dioxide based slag system may pick up titanium that has been reduced from the slag at high arc temperatures experienced during welding. It has been found that such titanium may be detrimental to the notch toughness of the weld especially in the stress relieved condition.

An alternative welding electrode is described in United Kingdom Patent Application No. 8104020 filed February 10, 1981, (Publication No. A2068813) having a slag system which though based at least in part on titanium dioxide, is able to produce a weld which exhibits improved notch toughness and impact properties. The core of such electrode includes a slag forming system comprising from about 5 to about 9 percent titanium dioxide, from about 0.2 to 1.0 percent magnesium oxide, less than about 2 percent calcium fluoride, and from about .003 to .08 percent boron, based on the total electrode weight.

An objective of the present invention is to provide a flux-cored electrode similar to that described in United Kingdom Patent Application No. 8104020, but which utilizes

a titanium oxide based slag system which has little or no magnesium oxide. The weld from such electrode exhibits improved notch toughness and impact properties over conventional rutile based electrodes while maintaining good operating characteristics for welding in all positions.

An advantage of reducing or eliminating the amount of MgO in the core of an electrode, is that the feeding and agglomeration problems which may occur during manufacture of an electrode that contains fine MgO powder in the core, may be reduced.

Another advantage of reducing the amount of MgO in the core of the electrode, is the reduction of a compound which may absorb moisture that could be reduced in the arc and increase the possibility of hydrogen cracking. Thus, the present invention beneficially reduces the amount of hydrogen which may be present in the weld deposit.

A further advantage of the present invention is that improved notch toughness and impact properties can be attained with rutile based electrodes which contain little or no magnesium oxide.

Additionally, the reduction of MgO level in the core of an electrode reduces the overall cost of the electrode and may reduce the fume level produced during welding.

The present invention provides a welding electrode having a generally tubular ferrous metal sheath, and a core defined within the sheath for use in gas shield welding wherein the shielding gas consists of carbon dioxide, inert

gas or oxygen and inert gas mixtures, or mixtures thereof, <u>characterised in that</u> said core consists of, by total weight of the electrode,

from 3.0 to 12.0% titanium dioxide

from 0 to less than 0.2% magnesium oxide,

up to 2.0% calcium fluoride,

from 0.1 to 1.0% sodium oxide,

from 0.2 to 2.0% silicon,

from 0.5 to 4.5% manganese,

from 0.003 to 0.08% boron, and

the balance consisting of an alloy powder consisting of nickel, chrome, molybdenum or iron, or mixtures thereof.

The electrodes of the present invention includes a generally tubular ferrous metal sheath. The sheath is formed of the metal to be consumed and transferred to the weld. In a preferred embodiment the electrode sheath may be formed from cold rolled strip material. Such strip material may be formed into an intermediate semicircular shape. While the strip is in such semicircular configuration, the core material, preferably homogeneously mixed together, may be poured therein. Then the strip or sheath, is closed about the core materials. Where desired, the electrode may be drawn or rolled to sizes smaller than the originally formed electrode. It will be understood that such forming and drawing operations have the effect of compressing the core materials, eliminating any void spaces throughout the length of the electrode, and preventing shifting or segregation of the core materials

during shipment or use.

The core of the electrode of the present invention comprises a mixture of slag forming ingredients, deoxidizers, arc stabilizers, and alloying ingredients. Additionally, iron powder may also be added to the core of the flux-cored electrode of the present invention to increase the deposition rate.

The slag forming system of the electrodes of the present invention is based on the ozide of titanium, TiO_2. More particularly the slag forming ingredients in the core of the electrode include from 3.0 to 12.0 percent titanium dioxide. The percentages stated herein are based on the total electrode weight unless specified to the contrary. Preferably titanium dioxide in the core comprises from 6.0 to 8.0 percent, e.g., 6.25 to 7.75 percent, of the total weight of the electrode. The titanium dioxide does not have to be in the pure form, but can be in other forms such as alkali metal titanates, leucoxene, and the like.

The slag forming system of the present invention contains little or no magnesium oxide. In particular, the core of the electrode contains less than 0.2 percent magnesium oxide, MgO. The prior art, particularly United Kingdom Patent Application No. 8104020 taught that MgO must be present in the core of such electrode in amounts of from about 0.2 to about 1.0 percent. It has been found that less than 0.2 percent MgO can be utilized in the core of the electrode, and yet the impact properties of the weld deposited by the electrode are improved over conventional titanium

dioxide based slag system.

The slag forming system of the present invention further contains less than 2.0 percent calcium fluoride, CaF_2. The clacium fluoride contributes to the cleanliness of a weld deposit, and increases the viscocity of the slag which covers and protects the weld metal from the atmosphere. The calcium fluoride together with the titanium dioxide provides a slag viscosity necessary to support the molten metal during welding especially during welding in positions other than horizontal.

The oxide of the sodium Na_2O, in the range of from 0.10 to 1.0 percent, is also added to the core of the electrode. Sodium oxide serves as an arc stabilizer during welding and increases the basicity of the slag.

Basicity is an index of the oxygen potential of the flux system. It is commonly represented as a ratio of the basic oxides (including alkali oxides and other more thermodynamically stable oxides) to the acid oxides. Basicity is commonly represented by an equation such as:

$$\text{Basicity Index} = \frac{CaO + CaF_2 + MgO + K_2O + Na_2O + 1/2\ (MnO + FeO)}{SiO_2 + 1/2\ (Al_2O_3 + TiO_2 + ZrO_2)}$$

It is known that welding electrode flux compositions with a higher basicity have less inclusions and a potential for better toughness. Conversely, flux compositions with a lower basicity tend to have better wetting characteristics. Wetting characteristics is generally defined as the ability to form a good bond with the base material and form a deposit with a smooth surface profile. Also, lower basicity flux compositions are more

likely to have all-position welding capability. As discussed above, an advantage of this invention is the provision of an improved slag system having the beneficial properties of the basic fluxes while maintaining the all-position capability and good wetting characteristics of the acid fluxes. Furthermore, improved impact properties are maintained even though little or no magnesium oxide is utilized in the slag system of the present invention.

Deoxidizers and alloying ingredients in the core of the welding electrode of the present invention include from 0.20 to 2.0 percent and preferably 0.5 to 1.5 percent, silicon, from 0.50 to 4.5 percent, and preferably 1.5 to 3.0 percent manganese, and from 0.003 to 0.080 percent, and preferably 0.01 to 0.03 percent boron. Additional metals, including iron, nickel, chrome and/or molybdenum powder alloys, may be added to the core of the electrode, e.g., in an amount of 0.5 to 5.0 percent, to produce low alloy weld deposits. The silicon and manganese may be added to the core in a combined force such as ferrosilicon, ferromanganese, ferromanganese-silicon, calcium silicide, and the like. The manganese and the silicon in the core deoxidize the weld deposit; and the silicon further contributes to the out-of position capabilities of the electrode by forming silicon oxides in the arc during welding, thereby increasing the viscosity and support capability of the slag.

However, it should be noted that silicon may have a detrimental effect on deposit toughness, as may be measured by a Charpy V-notch impact test, and, therefore the silicon content should be minimized if good toughness is a primary goal, especially after stress relief treatments. But some silicon is necessary to deoxidize the weld deposit, control the slag viscosity a d freezing characteristics, and promote the good fusion of the weld deposit to the base plate and with a smooth contour.

As taught in United Kingdom Patent Application No. 8104020, the specified additions of the microalloy boron in the titanium dioxide slag based electrode reduce the detrimental effect which titanium is known to have on the impact properties and notch toughness of a weld deposit. Welds deposited with conventional electrodes having a slag forming system based on titanium dioxide can contain titanium which is reduced from the slag at high arc temperatures.

Such titanium, typically present in the deposited weld in a range of from about 0.02 to 0.07 percent, is detrimental to the notch toughness of the weld, especially in the stress relieved condition. The detrimental effect of titanium is attributed to the precipitation of titanium at the grain boundaries of the weld deposit, perhaps in the form of a carbonitride.

It is also known that the heat input of the flux-cored welding process, when welding with a conventional titanium dioxide slag based electrode, results in the formation of a large percentage of grain boundary proeutectoid

ferrite. Acicular ferrite is also found between the long columnar grains of such proeutectoid ferrite. Large percentages of proetectoid ferrite has been found to be detrimental to the impact properties of a deposited weld since they provide areas which offer little or no resistance to the propagation of a crack.

Welds deposited with the electrode of the present invention have been found to exhibit improved notch toughness and impact properties; more particularly, the titanium has less of an adverse effect on the impact properties of a weld deposit when boron has been added to the core of the electrode. It appears that the titanium acts to provide the internal shielding necessary to protect the boron from oxidation or forming a nitride. Also, the boron in the electrode of the present invention promotes grain refinement. In particular, when boron, in the range of from 0.003 to 0.08 percent of the total electrode weight, is added to the core of the electrode, less proeutectoid ferrite, and more acicular ferrite is formed during sloidification of the weld. Also, with the electrode of the present invention, the remaining proeutectoid ferrite grains become discontinuous, thus further improving the impact properties of the deposited weld.

A gas shield is provided about the arc when welding with the electrode of the present invention. Shielding gases may include, by way of example, carbon dioxide, carbon dioxide - argon mixtures, and argon - oxygen mixtures. It has also been found that a current value in a range of from about 150 to 300 amperes at about 20 to 30 volts is sufficient

to weld with the electrodes of the present invention, particularly in the vertical position.

Table I below sets forth the chemical composition of an exemplary electrode of the present invention and one electrode with a conventional titanium dioxide slag system. The only major difference between these electrodes is the addition of boron to the electrode of Example 2.

TABLE I

Composition

Electrode Constituents	Amount (% of total electrode weight)	
	Example 1	Example 2
TiO_2	7.35	7.00
MgO	-	-
CaF_2	-	-
Na_2O	0.26	0.25
Si	1.08	1.03
Mn	2.84	2.70
B	-	0.02
Fe	remainder	remainder

The chemistry of the welds deposited with the electrodes set forth in the above examples, with a carbon dioxide shielding gas and a current value of about 200 amperes at about 24 volts, are set forth in Table II below. It should be understood that other welding parameters would be optimum for welding in other positions and with different shielding gases.

TABLE II

Weld Deposit Constituents	Amount (% by weight)	
	Example 1	Example 2
C	.066	.064
Mn	1.23	1.29
Si	.46	.49
P	.006	.006
S	.018	.019
Ti	.031	.035
B	-	.007

The as-welded physical properties of the welds specified in the above examples for both flat and vertical welding positions are set forth in Table III below:

TABLE III

	Example 1		Example 2	
	Flat	Vertical-up	Flat	Vertical-up
Mechanical Properties				
Yield Strength (ksi)	82.0	68.8	85.6	71.3
Tensile Strength (ksi)	93.2	82.1	92.0	84.4
Elongation (%)	26	26	26	28
Reduction of Area (%)	64	68	66	67
Average CVN Impacts				
22°C(+72°F)(ft. lbs)	73	76	89	97
-18°C(0°F)(ft.lbs)	45	41	64	72
-29°C(-20°F)(ft.lbs)	30	23	57	55

Table IV, below, sets forth the chemical composition of another exemplary electrode (Example 3) of the present invention, and that of an electrode with MgO and CaF_2 in the ranges disclosed in United Kingdom Patent Application No. 8104020 referenced above (Example 4). This table shows the acceptability of elimination of the MgO, and

optionally th CaF_2, from the slag system.

TABLE IV

Electrode Constituents	Amount (% of total electrode weight) Example 3	Example 4
TiO_2	7.40	7.32
MgO	0.52	-
CaF_2	0.07	-
Na_2O	0.22	0.22
Si	0.92	0.91
Mn	1.72	1.70
B	0.019	0.019
Fe	Remainder	Remainder

Weld deposit chemistries provided by welding with electrodes set forth in the above examples with a 75% argon/25% CO_2 shielding gas, are set forth below in Table V:

TABLE V

Weld Deposit Constituents	Amount (% by weight)	
	Example 3	Example 4
C	.045	.042
Mn	1.08	1.05
Si	.55	.56
P	.005	.005
S	.019	.018
Ti	.04	.04
B	.007	.007

The as-welded (AW) and stress relieved (SR) physical properties of welds deposited in the flat position set forth in examples 3 and 4 are shown in Table VI below:

TABLE VI

	Example 3 AW	Example 3 SR*	Example 4 AW	Example 4 SR*
Mechanical Properties				
Yield Strength (ksi)	72.5	67.8	72.3	67.8
Tensile Strength (ksi)	83.7	81.4	83.4	80.9
Elongation (%)	27	29	29	29
Reduction of Area (%)	67	69	73	74
Average CVN Impacts				
22°C(+72°F) (ft.lbs.)	103	106	89	100
-18°C(0°F) (ft.lbs.)	60	53	53	44
-46°C(-50°F) (ft.lbs.)	37	24	34	23

*Stress relieved 8 hours at 1125°F(607°C).

The following examples in Table VII further demonstrate the acceptability of eliminating magnesium oxide and optionally calcium fluoride from the slag system of the electrodes of the present invention. Only a minor reduction in impact properties occurs when MgO and CaF_2 are removed from the slag system.

TABLE VII

Slag Constituents in the Core (% of Total Electrode Weight)		Example 5	Example 6
TiO_2		7.24	7.33
CaF_2		0.07	-
Na_2O		0.39	0.32
MgO		0.53	-
Average CVN Impact Strength (ft. lbs) with CO_2 shielding gas, vertical position			
Stress relieved 8 Hours at 1125°F (607°)	0°F(-18°C)	69	58
	-20°F(-29°C)	58	45

CLAIMS:

1. A welding electrode having a generally tubular ferrous metal sheath, and a core defined within the sheath for use in gas shield welding wherein the shielding gas consists of carbon dioxide, inert gas, or oxygen and inert gas mixtures, or mixtures thereof, characterised in that said core consists of, by total weight of the electrode,

from 3.0 to 12.0% titanium dioxide
from 0 to less than 0.2% magnesium oxide
up to 2.0% calcium fluoride,
from 0.1 to 1.0% sodium oxide
from 0.2 to 2.0% silicon,
from 0.5 to 4.5% manganese
from 0.003 to 0.08% boron, and
the balance consisting of an alloy powder consisting of nickel, chrome, molybdenum or iron, or mixtures thereof.

2. A welding electrode according to claim 1, wherein the core comprises from 6.0 to 8.0% titanium dioxide.

3. A welding electrode according to claim 2, wherein the core comprises from 6.25 to 7.75% titanium dioxide.

4. A welding electrode according to claim 1, 2 or 3, wherein the core comprises from 0.5 to 1.5% silicon.

5. A welding electrode according to any one of the preceding claims, wherein the core comprises from 1.5 to 3.0% manganese.

6. A welding electrode according to any one of the

preceding claims. wherein the core comprises from 0.01 to 0.03% boron.

7. A welding electrode according to any one of the preceding claims, wherein the core comprises from 0.5 to 5.0% of an alloy powder, consisting of nickel, chrome, molybdenum or iron or mixtures thereof.

8. A welding electrode having a generally tubular ferrous metal sheath, and a core defined within the sheath for use in gas shield welding wherein the shielding gas consists of carbon dioxide, inert gas, oxygen and inert gas mixtures or mixtures thereof, said core consisting essentially of, by total weight, of the electrode,

from 6.0 to 8.0% titanium dioxide,
from 0.04 to 0.09% calcium fluoride,
from 0.2 to 0.4% sodium oxide,
from 0.5 to 1.5% silicon,
from 1.5 to 3.0% manganese, and
from 0.01 to 0.03% boron.

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European Patent Office

EUROPEAN SEARCH REPORT

Application number

EP 82 30 0511

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl. 3)
X	FR-A-2 351 753 (CATERPILLAR) * claims 11-15 * & GB - A - 1 517 892 ---	1	B 23 K 35/368 B 23 K 35/30
A	GB-A-1 079 710 (MUREX) ---		
A	FR-A-2 220 341 (KOBE STEEL) ---		
A,D	US-A-3 868 487 (Y. ITO et al.) ---		
A,D	US-A-3 924 091 (H. SUZUKI et al.) ---		
A,D	US-A-4 029 934 (A. CLARK et al.) ---		TECHNICAL FIELDS SEARCHED (Int. Cl. 3)
A,D	US-A-4 125 758 (M. DISHI et al.) ---		B 23 K
A,D	US-A-3 051 822 (A.A. BERNARD et al.) ---		
A	DE-A-2 320 939 (CHEMETRON) & US - A - 3 843 867 (Cat.A,D) ---		
	-/-		

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	09-09-1982	MOLLET G.H.J.

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
A : technological background
O : non-written disclosure
P : intermediate document

T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons

& : member of the same patent family, corresponding document

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European Patent Office

EUROPEAN SEARCH REPORT

Application number

EP 82 30 0511

Page 2

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl. 3)
A,P D	GB-A-2 068 813 (CHEMETRON) -----		
			TECHNICAL FIELDS SEARCHED (Int. Cl. 3)

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	09-09-1982	MOLLET G.H.J.

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T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons

& : member of the same patent family, corresponding document

EPO Form 1503. 03.82

PATENT SPECIFICATION

1,056,804

NO DRAWINGS

1,056,804

Date of Application and filing Complete Specification: May 19, 1965.
No. 21196/65.
Application made in Netherlands (No. 6405698) on May 22, 1964.
Complete Specification Published: Feb. 1, 1967.

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13Y,

ERRATA

SPECIFICATION No. 1,056,804

Page 2, line 80, *after* "and" *insert* "in"
Page 3, line 57, *for* "wsa" *read* "was"
Page 4, Table, Experiment No. 17, column 7,
for "0.26" *read* "0.36"
Page 5, line 24, *for* "thea" *read* "the"
Page 5, line 42, *for* "uand" *read* "and"

THE PATENT OFFICE
6th March 1967

PATENTS ACT, 1949

SPECIFICATION NO. 1,056,804

In accordance with the Decision of the Superintending Examiner, acting for the Comptroller-General, dated 5 March 1970 this Specification has been amended under Section 14 in the following manner:-

Page 1 line 78 page 5 line 4 *for* "10:1" *read* "9:1"

THE PATENT OFFICE
12 May 1970

R 124007/4

said material may also contain, if desired, iron powder and/or alloying elements. Titanium dioxide among other elements, may be used as a material which is suitable for the formation of slag.

A flux-cored wire electrode is also known having a core which substantially consists of pre-fused titanium dioxide, silicon dioxide and manganese oxide as slag-forming elements in such quantities that these elements constitute more than approximately 14% by weight of the electrode.

The use of such large quantities of slag-forming elements involves drawbacks, *inter alia* in that there is a lowering of efficiency during welding. Further, when known flux-cored electrodes in the form of flux-cored wires are used, welds are often obtained of a poor quality, and in addition, these known electrodes are not very suitable for making fillet

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cored welding electrode, in the form of a flux-cored wire, having a tubular casing of which the main constituent is iron, said electrode containing manganese and at least one other strongly reducing metal and/or silicon as constituents of the casing and/or core, the core of the said electrode having a titanium dioxide- and silicon dioxide-containing slag-forming part, the ratio of the quantities by weight of titanium dioxide and silicon dioxide present in the said slag-forming part of the core is equal to or lies between 10 : 1 and 1 : 1.5, the total quantity by weight of titanium dioxide and silicon dioxide together constituting at least 3.5% by weight and the said slag-forming part of the core constituting at most 9% by weight of the total weight of the welding electrode.

The present invention also relates in another aspect to a method of electric arc welding with

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1,056,804

NO DRAWINGS

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Index at acceptance:—B3 R(32G, 37A1A, 37A1D); C7 M(202, 483, 486, 22Y, 222, 503, 506, 23Y, 232, 513, 516, 24Y, 242, 523, 526, 30Y, 583, 586, 42Y, 703, 43Y, 713, 464, 466, 469, 740, 743, 749, 771, 780, 781)

Int. Cl.:—B 23 k

COMPLETE SPECIFICATION

Improvements in or relating to Flux-Cored Welding Electrodes for Electric Arc Welding

We, PHILIPS ELECTRONIC AND ASSOCIATED INDUSTRIES LIMITED, of Abacus House, 33 Gutter Lane, London, E.C.2, a British Company, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:

THE INVENTION relates to a flux-cored welding electrode in the form of a flux-cored wire for use in electric arc welding in an atmosphere of a protective gas and to a method of electric arc welding with the use of such an electrode.

It is known to use a method of electric arc welding with a protective gas for welding workpieces which are principally composed of iron with a welding electrode consisting of a tubular casing of which the main constituent is iron and a core consisting of a non-hygroscopic, subtsantially hydrogen-free material, which material is suitable for the formation of slag, and a deoxidizing material. The said material may also contain, if desired, iron powder and/or alloying elements. Titanium dioxide among other elements, may be used as a material which is suitable for the formation of slag.

A flux-cored wire electrode is also known having a core which substantially consists of pre-fused titanium dioxide, silicon dioxide and manganese oxide as slag-forming elements in such quantities that these elements constitute more than approximately 14% by weight of the electrode.

The use of such large quantities of slag-forming elements involves drawbacks, *inter alia* in that there is a lowering of efficiency during welding. Further, when known flux-cored electrodes in the form of flux-cored wires are used, welds are often obtained of a poor quality, and in addition, these known electrodes are not very suitable for making fillet welds in the horizontal-vertical position or for making welds in the overhead position, for example, fillet welds.

It is an object of the present invention to provide a welding electrode of which the main constituent is iron and which is in the form of a flux-cored wire, suitable for electric arc welding with the use of a protective gas of workpieces which are principally made of iron in which the said drawbacks do not occur.

The welding electrode of the invention will have a core containing as a constituent part substances which are suitable for the formation of slag to cover the molten welding metal as a coherent layer and which can easily be removed after cooling. This constituent part will hereinafter be referred to as the slag forming part of the core. It consists at least of titanium dioxide and silicon dioxide and may also include alkali metal oxide and/or aluminium oxide or of compounds which are composed of two or more of the said oxides.

According to the present invention, in a flux-cored welding electrode, in the form of a flux-cored wire, having a tubular casing of which the main constituent is iron, said electrode containing manganese and at least one other strongly reducing metal and/or silicon as constituents of the casing and/or core, the core of the said electrode having a titanium dioxide- and silicon dioxide-containing slag-forming part, the ratio of the quantities by weight of titanium dioxide and silicon dioxide present in the said slag-forming part of the core is equal to or lies between 10 : 1 and 1 : 1.5, the total quantity by weight of titanium dioxide and silicon dioxide together constituting at least 3.5% by weight and the said slag-forming part of the core constituting at most 9% by weight of the total weight of the welding electrode.

The present invention also relates in another aspect to a method of electric arc welding with

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the use of such an electrode.

The tubular casing of the welding electrode is mainly of iron and may consist, for example, of soft steel or of an alloyed steel, for example, 18-8 chrome-nickel steel.

The casing may have different shapes, for example, it may be cylindrical or it may have a rectangular cross-section. The casing can be obtained, for example, according to a method known *per se* by wrapping a strip; in the wrapping process the material of the core may be incorporated in the wire.

The welding electrode according to the invention can particularly suitably be used in the form of an endless wire as a continuous consumable electrode particularly for automatic or semi-automatic welding processes.

Usually the reducing elements will be distributed between the casing and the core. In this manner the quantity of reducing elements required can easily be adapted to the requirements of a particular workpiece. The same holds for alloying elements which are to be incorporated in the electrode to adapt the composition thereof to the requirements of the workpiece.

For welding workpieces made principally of iron and, for example, consisting of steel which is not completely deoxidized, the welding electrode should contain at least 0.3 and at most 2.5% by weight of manganese and at least 0.3 and at most 1.5% by weight of silicon. Silicon may be replaced wholly or partially by titanium. For example, 1.6% by weight of manganese and 0.8% by weight of silicon is used. These elements may be suitably applied in the form of ferro alloys or as silicon manganese.

The core of the welding electrode may contain, in addition to the slag-forming part, iron powder (or a powder of another metal or of a mixture of metals) up to approximately 95% by weight of the core, and/or if desired alloying constituents, for example, nickel or chromium, or, for example, a powder of an alloyed steel, for example 18-8 chrome-nickel steel.

The choice of the ratio of the respective masses of casing and core is comparatively arbitrary. For practical purposes, the wall thickness of the casing will invariably be chosen to be so that a wire of sufficient strength is obtained.

In the method according to the invention carbon dioxide will preferably be used as the protective gas. Alternatively, carbon dioxide containing mixtures and, for example, a mixture of 95% by volume of carbon dioxide and 5% by volume of oxygen, a mixture of 85% by volume of argon and 15% by volume of carbon dioxide, or a mixture of 80% by volume of argon, 15% by volume of carbon dioxide and 5% by volume of oxygen may be used.

The welding electrode is particularly suitable for welding workpieces of steel which is not completely deoxidized with the use of a carbon dioxide-containing protective gas and in particular of a protective gas consisting substantially entirely of carbon dioxide.

Good results are obtained in particular with electrodes in which the ratio of the quantities by weight of titanium dioxide and silicon dioxide is substantially equal to or lies between 5 : 1 and 1 : 1.5 and in particular with electrodes in which this ratio is substantially equal to or lies between 2 : 1 and 1 : 1. This holds in particular for electrodes in which the slag forming part of the core constitutes 5—8% by weight, and particular in which this part is approximately 5% by weight of the whole electrode. With the use of such electrodes, which contain, for example, 1.6% by weight of manganese and 0.8% by weight of silicon, good welds having a smooth even appearance can be obtained on workpieces of, for example, non-alloyed steel or low-alloyed steel, while using carbon dioxide as the protective gas. These welds are also obtainable even when upward welding in the vertical position occurs. Very good fillet welds, also when making welds in the overhead position, can be obtained with such electrodes. The slag can very readily be removed; usually, the slag releases on cooling. The point where the weld joins the workpiece is smooth.

It has been found that what was said in the preceding paragraph holds in particular for electrodes according to the invention in which slag-forming part of the core also contains potassium oxide or both potassium oxide and aluminium oxide and in particular if the latter oxides and part of the silicon dioxide are used in the form of potash feldspar ($K_2O.Al_2O_3.6SiO_2$). In this case the quantities by weight of the oxides are preferably chosen to be such that the ratio of that of silicon dioxide to that of potassium oxide or to that of this oxide and aluminium oxide together exceeds 2.3.

Instead of potassium oxide alternately another alkali oxide, for example sodium oxide, may be used.

The oxides to be used, and this holds in particular for the alkali oxides, will preferably be used in the form of compounds which are not hygroscopic. For this reason also, potash feldspar is to be preferred.

When using alkali oxides in the form of compounds which are more or less hygroscopic, adequate measures have to be taken during the manufacture of the welding electrodes to avoid moisture penetrating the core. For example, alkali oxide may be used in a bound form as carbonates, silicates, titanates or aluminates of potassium, sodium or caesium. When using a titanate, part of the titanium dioxide is used in a bound form; the same holds for silicon dioxide and aluminium oxide respectively when using silicates and aluminates respectively.

This fact should be taken into account when dosing the free oxides.

In order that the invention may readily be carried into effect, it will now be described in greater detail, by way of example, with reference to the following specific examples.

The following table shows the composition of the said slag-forming part of the core for a number of tested electrodes according to the invention. The quantities of the various oxides are given in percentages by weight of the welding electrode in question. The same applies for the iron (as powder), manganese and silicon present in the material of the core. Manganese was added as siliconmanganese, silicon as ferrosilicon.

In experiments 1 to 5 inclusive titanium dioxide and silicon dioxide only were used as slag-forming constituents; in experiments 6 to 8 inclusively and 20 to 22 inclusively potassium oxide, aluminium oxide and part of the silicon oxide were added as potash feldspar. In experiment 19 sodium oxide, aluminium oxide and part of the silicon oxide was added as soda feldspar (0.5% by weight). In experiment 22 the core contained 0.35% by weight of titanium. In experiment 24 the core contained 18-8 chrome-nickel-steel (26% by weight of the electrode) instead of iron powder. In this latter experiment the content of manganese and silicon was adapted to the 18-8 chrome-nickel steel to be welded. The casing of the welding wires consisted of a soft steel containing 0.23% by weight of Mn, less than 0.1% by weight of Si and less than 0.1% by weight of C. In experiments 1 to 23 inclusively welding was performed on workpieces consisting of semi-killed steel (0.5% by weight of Mn, 0.05% by weight of Si and 0.10% by weight of C). In experiments 13, 20 and 21 welding was also carried out on workpieces consisting of killed steel (1.4% by weight of Mn, 0.5% by weight of Si, 0.2% by weight of C). In experiments 20 and 21 welding was performed in addition on workpieces consisting of another killed steel (1.2% by weight of Mn, 0.07% by weight of Si, 0.12% by weight of C). In experiment 24 welding was performed on workpieces consisting of chrome-nickel steel (18% of Cr, 8% of Ni).

The experiments were carried out with welding electrodes of 1.2 and 1.8 mm diameter. In experiments 1 to 24 inclusively welding was performed with an electrode diameter of 1.8 mm with 360 A direct current (electrode as the positive pole); in experiment 11 welding wsa also performed wtih the electrode as the negative pole. In experiments 11, 14, 16 and 17 (electrode diameter 1.8 mm) welding was also performed with 360 A alternating current. In experiment 5 (electrode diameter 1.8 mm) welding was also performed with 260 A direct current (electrode as the positive pole); in experiments 9 and 18 (electrode diameter 1.2 mm) welding was also performed with 200 A direct current (electrode as the positive pole). Fillet welds in the horizontal position and upward welding in the vertical position were mainly made. In experiments 1 to 24 inclusive carbon dioxide was used as the protective gas (the quantity of gas varied from 10 to 20 litres per minute). With electrodes of experiment 11 also gas mixtures of other compositions were used, for example, (A) 80% by volume of argon + 15% by volume of carbon dioxide + 5% by volume of oxygen, (B) 95% by volume of carbon dioxide + 5% by volume of oxygen and (C) 90% by volume of carbon dioxide + 10% by volume of oxygen. In this case the quantity of gas was approximately 20 litres per minute.

Particularly good results were obtained with welding electrodes of the experiments 7, 11, 18 and 21 and especially with those of experiment 10.

TABLE

Experiment No.	Elements of the core						
	Fe	Mn	Si	TiO_2	SiO_2	K_2O	Al_2O_3
1	22	1.45	0.8	4.5	0.5		
2	21	1.45	0.8	4.0	1.0		
3	20	1.45	0.8	3.5	1.5		
4	20	1.45	0.8	2.5	2.5		
5	21	1.45	0.8	2.0	2.0		
6	23	1.45	0.8	4.5	0.52	0.09	0.09
7	23	1.45	0.8	4.0	0.82	0.09	0.09
8	22	1.45	0.8	3.5	1.32	0.09	0.09
9	21	1.45	0.8	3.0	1.82	0.09	0.09
10	21	1.45	0.8	2.5	2.32	0.09	0.09
11	22	1.45	0.8	3.0	1.65	0.17	0.18
12	20	1.45	0.8	2.5	2.15	0.17	0.18
13	20	1.45	0.8	2.0	2.65	0.17	0.18
14	22	1.45	0.8	3.0	1.47	0.25	0.28
15	20	1.45	0.8	2.5	1.97	0.25	0.28
16	20	1.45	0.8	2.0	2.47	0.25	0.28
17	20	1.45	0.8	2.0	2.30	0.34	0.26
18	17	1.45	0.8	4.8	2.64	0.27	0.29
19	22	1.45	0.8	2.5	2.34		0.10
20	23	2.15	0.4	3.0	1.65	0.17	0.18
21	21	1.05	1.25	3.0	1.82	0.09	0.09
22	20	1.45	0.6	2.5	2.15	0.17	0.18
23	23	1.45	0.8	0.3	1.82	0.09	0.39
24		1.20	1.15	2.5	1.97	0.25	0.28

WHAT WE CLAIM IS:—

1. A flux-cored welding electrode, in the form of a flux-cored wire, having a tubular casing of which the main constituent is iron, said electrode containing manganese and at least one other strongly reducing metal and/or silicon as constituents of the casing and/or the core, the core of the said electrode having a titanium dioxide- and silicon dioxide-containing slag-forming part, in which the

ratio of the quantities by weight of titanium dioxide and silicon dioxide present in the slag-forming part of the core is equal to or lies between 10 : 1 and 1 : 1.5, the total quantity by weight of titanium dioxide and silicon dioxide together constituting at least 3.5% by weight and the said slag-forming part of the core constituting at most 9% by weight of the total weight of the welding electrode.

2. A welding electrode as claimed in Claim 1, in which the ratio of the quantities by weight of titanium dioxide and silicon dioxide present in the said slag-forming part of the core is substantially equal to or lies between 5 : 1 and 1 : 1.5.

3. A welding electrode as claimed in Claim 2, in which the ratio of the quantities by weight of titanium dioxide and silicon dioxide present in the said slag-forming part of the core is substantially equal to or lies between 2 : 1 and 1 : 1.

4. A welding electrode as claimed in Claims 1 to 3, in which the said slag-forming part of the core is equal to or lies between thea values 5% to 8% by weight of the welding electrode.

5. A welding electrode as claimed in Claims 1 to 4, in which the said slag-forming part of the core contains free or bound alkali oxide and the ratio of the quantities by weight of silicon dioxide to alkali oxide exceeds 2.3.

6. A welding electrode as claimed in Claim 5, in which the alkali oxide is potassium oxide.

7. A welding electrode as claimed in Claims 5 and 6, in which the said slag-forming part of the core includes aluminium oxide and the ratio of the quantity by weight of silicon dioxide and the total quantity by weight of alkali oxide and aluminium oxide together exceeds 2.3.

8. A welding electrode as claimed in Claim 7, in which the alkali oxide uand aluminium oxide and part of the silicon dioxide used in the said slag-forming part of the core is added in the form of an alkali feldspar.

9. A welding electrode as claimed in Claim 8, in which the alkali feldspar is potash feldspar.

10. A method of electric arc welding of workpieces consisting principally of iron, in an atmosphere of a protective gas, with the use of an electrode in one or more of the preceding Claims.

11. A method as claimed in Claim 10, in which the protective gas is a carbon-dioxide containing gas.

12. A method as claimed in Claim 11, in which the protective gas is carbon dioxide.

13. A welding electrode for electric arc welding substantially as herein described with reference to the specific examples.

14. A method of electric arc welding of workpieces substantially as herein described with reference to the specific examples.

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Leamington Spa: Printed for Her Majesty's Stationery Office, by the Courier Press (Leamington) Ltd.—1967. Published by the Patent Office, 25 Southampton Buildings, London, W.C.2. from which copies may be obtained.